MODELLING

OF

MICRO WIRE-EDM

A thesis submitted in partial requirements for the degree

Of

Bachelor of Technology

In

Mechanical Engineering

By

Ashutosh Mishra

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CERTIFICATE

This is to certify that this report, entitled "**MODELLING OF MICRO WIRE-EDM OPERATION"**, submitted by Ashutosh Mishra in partial fulfilment for the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other University or Institute for the award of any Degree or Diploma.

Place: **NIT, Rourkela**

Date:

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Rourkela, Odisha. 769008

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ABSTRACT

The objective of the present work is to calculate the metal removal rate (MRR) during a single spark micro WEDM process using finite element analysis in ANSYS software. The material used is Inconel 625.

Wire electrical discharge machining (WEDM) is a thermoelectric metal removal process which erodes material from the work piece by a series of discrete sparks between the metal wire electrode and the workpiece, immersed in a dielectric liquid medium. The spark discharges generated between the electrode and the workpiece result in complex two dimensional and three dimensional shapes along a numerically controlled path. The purpose of micro WEDM is to achieve better accuracy and stability while dealing with small sized workpieces.

Finite element method (FEM) modelling is a computer-aided technique for finding approximate solutions of partial differential equations and integral equations.

Keywords: **WEDM, MRR, ANSYS, FEM**

INTRODUCTION

Electrical discharge machining (EDM) is an important thermal erosion process which erodes material from the work piece by a series of discrete sparks between the electrode and the workpiece immersed in a dielectric liquid medium. Electrical energy is used directly to cut the material in final shape, through melting and subsequent vaporization. The molten material is then ejected and flushed away by the dielectric medium. The sparks occur at high frequency which continuously and effectively removes the work prices material by melting and evaporation. To initiate the machine process electrode and work piece are separated by a small gap known as 'spark gap' which results into a pulsed discharge causing the removal of material. The purpose of the dielectric is to provide a deionizing medium between the two electrodes, whose flow helps the removal of re-solidified debris and assures optimal conditions for spark generation.

In micro-wire EDM operation the work piece metal is cut with a special metal wire electrode which has been programmed via CNC to travel along a definite path. Spark discharges and generated between a small wire electrode and a work piece to produce complex two dimensional and three-dimensional shapes according to a NC path. The diameter of the wire electrode used ranges from 0.02 to 0.3 mm. Material can be removed from the workpiece through the movement of either the workpiece or the wire electrode. The mechanism of metal removal is similar to that in convectional micro EDM. The most prominent feature of a moving wire is that a complicated cut-out can be early machined without using a forming electrode.

The CNC system of wire EDM provides pulse generator control, wire feed, wire tension control, machining process control, geometric trajectory, and sequential control. The wire transport system helps in smooth wire transport and constant tension of wire.

Like any other thermal process, WEDM can result in surface damage of the workpiece material due to heat of the spark. At least three surface layers are formed during wire EDM process:

Recast layer: layer of molten material that has not been expelled from the workpiece

White layer: a rehardened solid layer formed as a result of rapid heating-cooling

Heat affected zone: a layer which does not melt during machining, but whose microstructure and mechanical properties are affected

These surface damages and wire ruptures are largely unavoidable, even by the most skilled workers, due to a large number of variables and the stochastic nature of the entire process. This is why most the wire EDM machines available today include some kind of optimized process controlling features, which help in achieving the optimized settings. However, completely eradicating the machining problems is not possible. Theoretical and numerical studies on EDM and wire EDM are rare, mainly due to the complex physics involved in the process.

Some important features of micro wire-EDM include,

1. The machine can be operated unattended for a long period of time (once the input parameters have been fed).

2. The electrode wear is negligible.

3. Geometric and dimensional tolerances are tight.

4. The machined surface is very smooth and has high accuracy.

5. Forming electrodes are not required to produce desired shapes.

6. Production of high precision straight holes is possible.

7. The only requirement of the material to be machined is that it should be electrically conductive.

8. Relative tolerance between punch and die is much higher and die life is extended.

Workpiece material – Inconel 625

Inconel is a family of super-alloys consisting of nickel and chromium as their predominant elements. Most Inconels contain small quantities of iron and molybdenum, niobium and other elements.

Inconel 625 is an important member of Inconel family. Its composition is as follows,

Nickel, 58%	Chromium, 20-23%
Molybdenum, 8-10%	Iron, 5%
Niobium, 3.15-4.15%	Others, balance

Inconel 625 has excellent corrosion resistance in a wide range of corrosive media, being especially resistant to pitting and crevice corrosion. It is extensively used for sea water applications (marine industries).

LITERATURE REVIEW

Hargrove et al. [1] determined the cutting parameters in wire EDM based on workpiece surface temperature distribution. Like any other thermal machining process, WEDM can result in surface damage of the workpiece due to heat of the spark. Hence they carried out an experiment to find the optimum machine parameters that will maintain a balance between cutting speed and minimum surface damage. The analysis of three different surface layers formed due to WEDM – recast layer, white layer, and heat affected zone – was done. The optimum cutting parameters were first calculated using FEM simulation and then experimentally verified.

Klocke et al. [2] presented useful examples of FEM application in different branches of manufacturing technology in their extensive research paper. They also simulated all the problems to present the results, which was achieved with much less effort thanks to FEM modelling.

Allen et al. [3] simulated the process of single spark micro-EDM on molybdenum to find the material removal rate. The model was then used to calculate the effect of EDM parameters on the crater dimension. Their study indicated the build-up of tensile residual stresses near the crater boundary in all directions. The effect of machining parameters like pulse current and pulse duration on the residual stresses was further studied by Biswas et al. [4] using ANSYS software.

Mahapatra et al. [7] demonstrated the adjustment of WEDM process parameters to achieve better MRR, surface finish, and cutting width simultaneously. After calculating the metal removal rate through experimentation, they applied the Taguchi method to optimize the parameters and output.

Tian et al. [9] presented a computer aided control system for process monitoring in micro wire-EDM. Yan et al. [8] implemented the fuzzy logic strategy for optimization of a similar control system for WEDM. They were able to obtain stable and high speed machining with their developed system.

Sarkar et al. [6] used the artificial neural network model to optimize experimental parameters in WEDM process. They used Y titanium aluminide alloy as their workpiece.

MODELLING PROCEDURE

The FEM modelling of the workpiece material has been carried out in ANSYS v12.1 software, after referring to the manual – Melting Using Element Death, University of Alberta [11].

Due to the two dimensional nature of the modelling, we shall make the following assumptions before proceeding,

1. An axisymmetric model has been considered.
2. A single spark experiment will be simulated in the software.
3. The material is homogenous and isotropic in nature.
4. Workpiece material is stress-free before wire-EDM.
5. The thickness of the material is much larger compared to its length and width.

The steps for modelling are detailed below.

Phase 1: **Preprocessing**

1. Open Mechanical APDL (ANSYS).
2. Go to File > Change Title and give a new title for the example.
3. We shall be dealing with a rectangular block of length 100 μm, width 20 μm, and thickness 1 mm. Also the spark radius is taken

as 5 µm. Since we shall be doing a 2D modelling, the thickness of the material will not be taken into consideration.

To create the rectangle, we go to Preprocessor > Modelling > Create > Areas > Rectangle.

4. Define the type of element (Thermal Solid, Quad 4node 55 – PLANE55) from Preprocessor > Element Type > Add/Edit/Delete. Click on Options and switch to the Axisymmetric view.

5. Enter the element material properties (thermal conductivity, specific heat, and density) in Preprocessor > Material Props > Thermal.

6. For FEM modelling we need to create a mesh. Here we have chosen an element edge length of 1 µm. To define the mesh size, go to Preprocessor > Meshing > Size Cntrls > ManualSize > Areas > All Areas…. The mesh can then be framed from Preprocessor > Meshing > Mesh > Areas > Free > "Pick All".

Phase 2: **Solution**

1. To define the analysis type, go to Solution > Analysis Type > New Analysis > Transient.

2. Turn on the Newton-Raphson solver by typing NROPT, FULL in the command line. This is necessary as the material can be removed from the model only when the N-R solver has been used.

3. To set the solution controls, go to Solution > Analysis Type > Sol'n Controls.

   Set the T_{on} time (2 μs) and T_{off} time (100 μs). Set the desired number of substeps and iterations (20 and 100).

4. To set the initial temperature (298 K) go to Solution > Define Loads > Apply > Initial Condit'n > Define > Pick All.

5. Now we have to apply the heat flux equation, which is

   Q(r) = (4.45*P*V*I)/(3.14*R^2)*exp(-4.5*(r/R)^2)

   Here, P is the percentage heat input, V is the voltage, I is the current, and R is the spark radius.

6. To solve the system, we go to Solution > Solve > Current LS.

Phase 3: **Postprocessing**

1. To read the results, go to General Postproc > Read Results > Last Sets.

2. The data that was gathered during analysis must now be input to a table, which can then be used by ANSYS to remove metal from the workpiece. To create the element table, go to General Postprocessor > Element Table > Define Tale > Add. Enter a new table name, and select DOF solution > temperature TEMP.

3. To start killing (removing) the element, go to Utility Menu > Select > Entities > Select Elements > By Results > From Full > OK. Use the previously created table from the list and enter the melting temperature (1623 K) in the appropriate field.

4. Restart the analysis from Solution > Analysis Type > Restart > OK, and use the *ekill,all* command to remove the molten material.

5. To view the results, Elements > Live Elem's > Unselect > Sele All > From Full. And then General Postproc > Plot Results > Contour Plot > Nodal Solu > DOF Solution > Temperature TEMP.

RESULTS AND DISCUSSION

Objective

To calculate the MRR of the given workpiece (Inconel 625) using FEM modelling on a single spark micro wire-EDM operation.

Available data

We use the following data for our modelling,

1. **Physical properties of Inconel 625**

   Density = 8,440 kg/m^3

   Melting temperature = 1,623 K

   Specific heat = 410 J/kg K

   Thermal conductivity = 9.8 W/m K

2. **Input parameters**

   Percentage heat input = 0.08%

   Voltage = 10 V

   Current = 1.5 A

   Spark radius = 5 µm

3. **Length of the sheet = 100 microns**

   Width of the sheet = 20 microns

4. **Thickness of the sheet = 1 mm (>> length and width)**

5. **Pulse-On Time (T_{on}) = 2 µs**

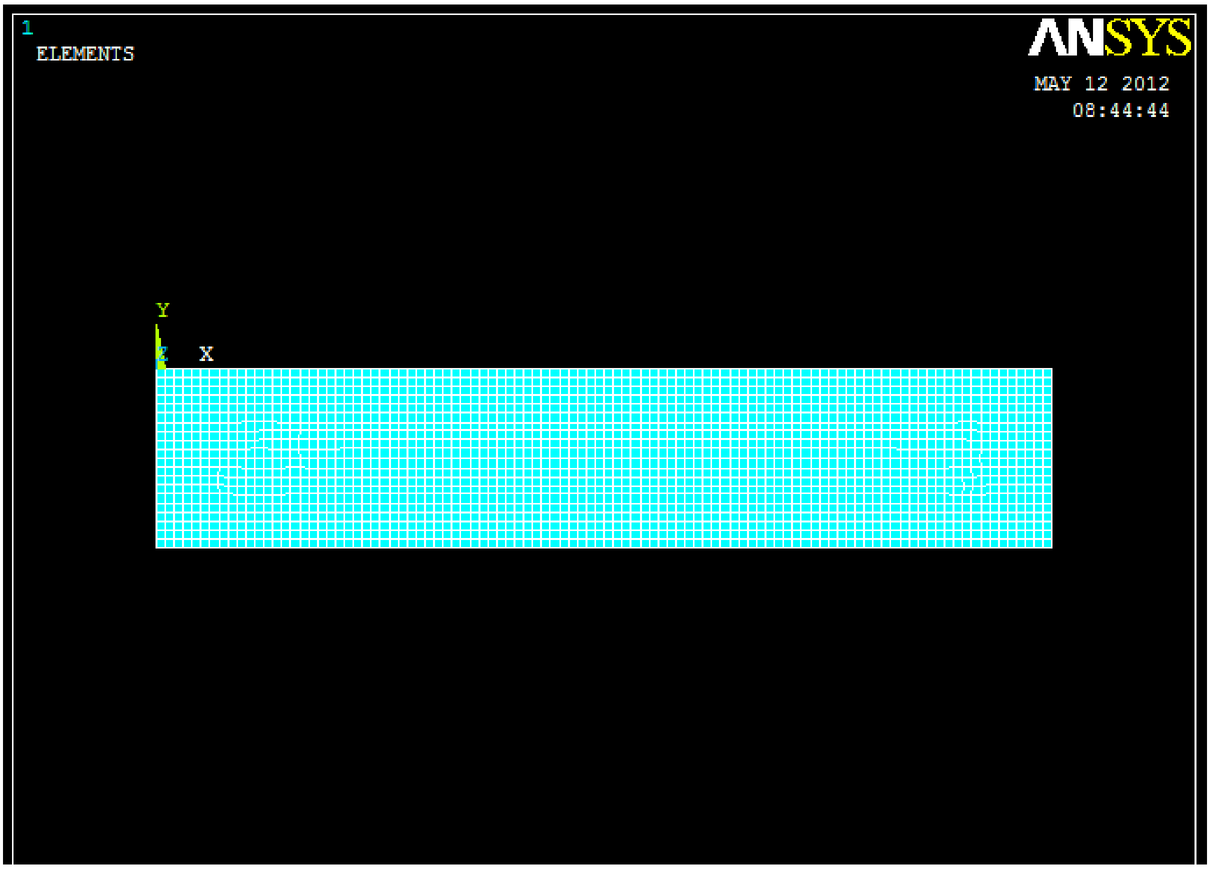
   Pulse-Off Time (T_{off}) = 100 µs

To calculate the material removal rate, we have to first calculate the total volume (C_v) of the elements that were killed (removed) during the modelling.

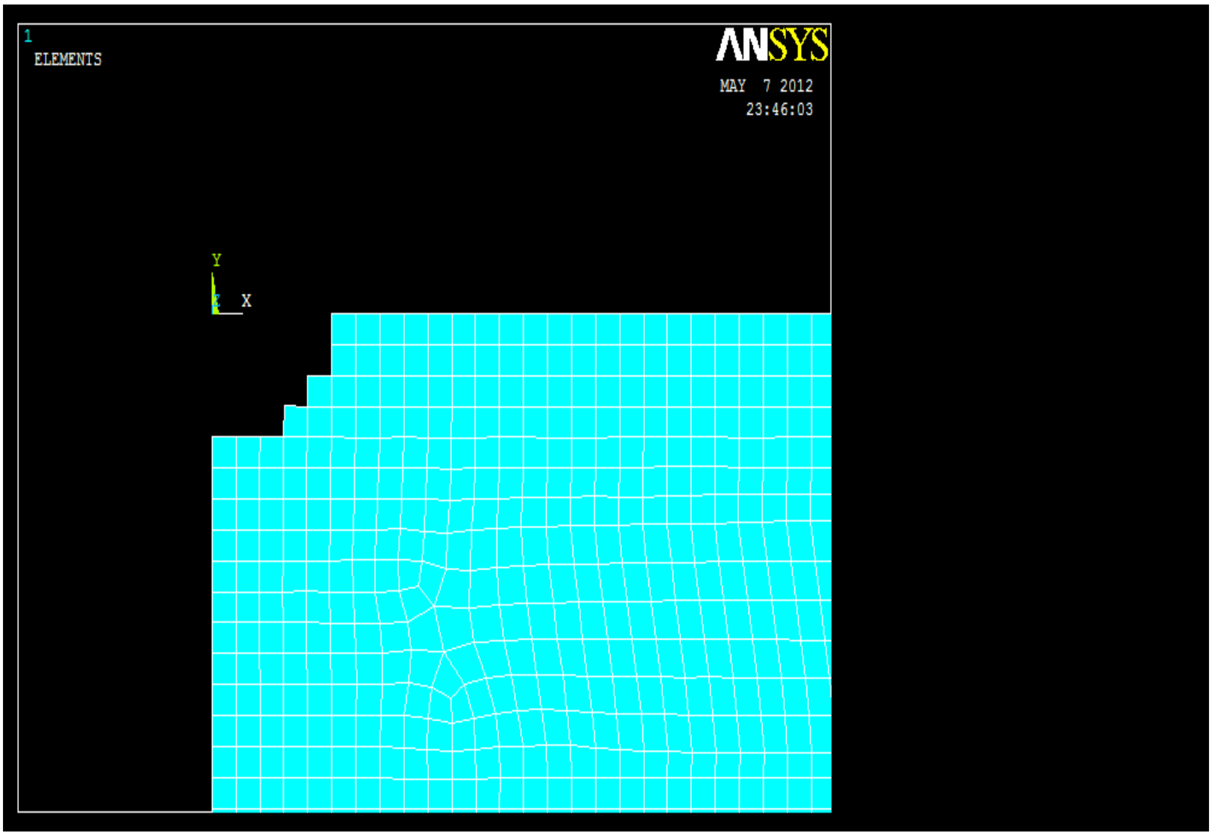
Then we use this formula to find MRR in mm^3 / spark.

$$\mathbf{(60 \times C_v) / \{(T_{on} + T_{off}) \times 10^3\}}$$

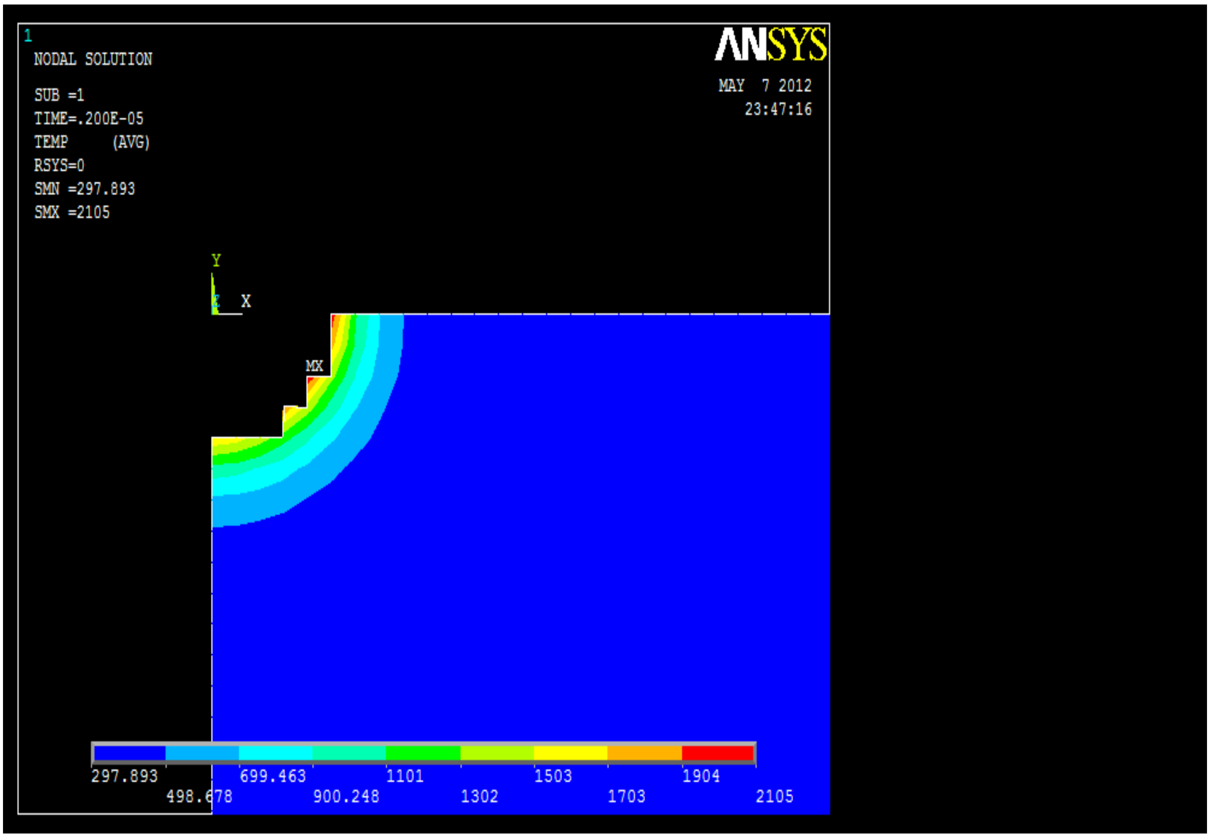
Modelling



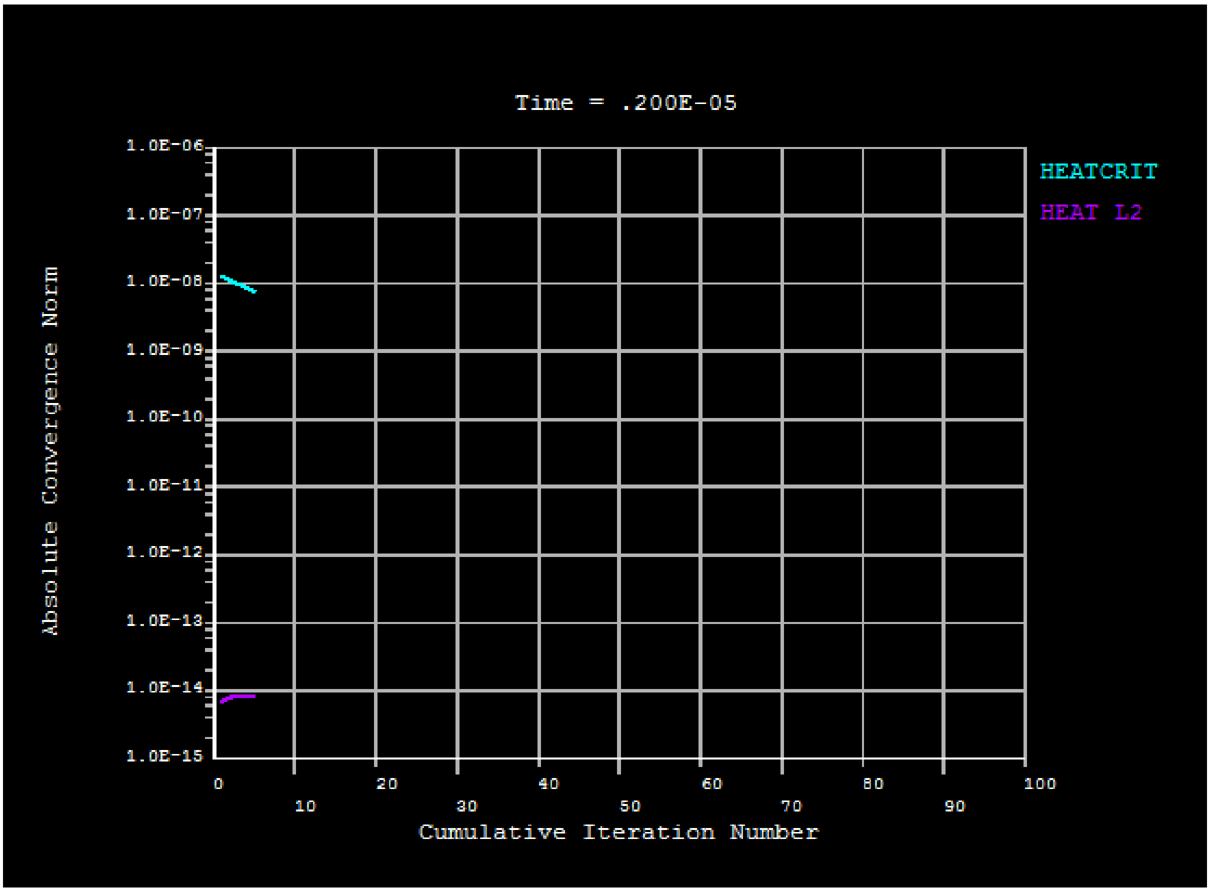
1. Initial mesh view of the workpiece



2. Mesh view of workpiece after metal removal (zoomed in)



3. Temperature profile of workpiece after metal removal



4. Iterations in ANSYS

Calculation

Element volume calculation (from model),

$$V_i = \pi\ (x_i - x_0)^2\ (y_i - y_{i-1})$$

Here we have four unit volumes,

$$V_1 = \pi\ (x_1 - x_0)^2\ (y_1 - y_0)$$

$$= \pi\ (3 \text{ x } 10^{-6} - 0)^2\ (10^{-6})$$

$$= 2.83 \text{ x } 10^{-17}\ m^3$$

$$V_2 = \pi\ (x_2 - x_0)^2\ (y_2 - y_1)$$

$$= \pi\ (4 \text{ x } 10^{-6} - 0)^2\ (10^{-6})$$

$$= 5.03 \text{ x } 10^{-17}\ m^3$$

$$V_3 = \pi\ (x_3 - x_0)^2\ (y_3 - y_2)$$

$$= \pi\ (5 \text{ x } 10^{-6} - 0)^2\ (10^{-6})$$

$$= 7.85 \text{ x } 10^{-17}\ m^3$$

$$V_4 = \pi\ (x_4 - x_0)^2\ (y_4 - y_3)$$

$$= \pi\ (5 \text{ x } 10^{-6} - 0)^2\ (10^{-6})$$

$$= 7.85 \text{ x } 10^{-17}\ m^3$$

Now,

$$\mathbf{C_v} = V_1 + V_2 + V_3 + V_4$$

$$= 23.56 \times 10^{-17}\ m^3 = 2.356 \times 10^{-8}\ mm^3$$

Material removal rate (MRR)

$$= (60 \times C_v) / \{(T_{on} + T_{off}) \times 10^3\}$$

$$\mathbf{= 1.38 \times 10^{-4}\ mm^3 / spark.}$$

The metal removed from ¼ of the given workpiece is $1.38 \times 10^{-4}\ mm^3$ / spark.

Therefore, **total MRR**

$$= 1.38 \times 10^{-4} \times 4\ mm^3 / spark.$$

$$= \mathbf{5.52 \times 10^{-4}\ mm^3 / spark.}$$

Hence, approximately $\mathbf{5.52 \times 10^{-4}\ mm^3}$ of molten material is removed from the given Inconel 625 workpiece in a single spark micro wire-EDM process.

REFERENCES

[1] S. Keith Hargrove, Duowen Ding; Determining cutting parameters in wire EDM based on workpiece temperature distribution, Int J Adv Manuf Technol, 2007

[2] Fritz Klocke, Thorsten Beck, Stefan Hopee, Tilo Krieg, Norbert Muller, Tobias Nothe, Hans-Willi Raedt, Kevin Sweeney; Examples of FEM application in manufacturing technology, JMPT, 2002

[3] Philip Allen, Xiaolin Chen; Process simulation of micro electro-discharge machining of molybdenum, JMPT 186, 2007

[4] Chanda Kumar Biswas, Mohan Kumar Pradhan; FEM of residual stress of EDMed surfaces

[5] K.H. Ho, S.T. Newman, S. Rahimifard, R.D. Allen; State of the art in wire electrical discharge machining (WEDM), IJMTM 44, 2004

[6] S. Sarkar, S. Mitra, I.K. Gomes, B. Bhattacharya; Modelling and optimization of WEDM in single pass cutting operation, ICME, 2005

[7] S.S. Mahapatra, Amar Patnaik; Optimization of WEDM process using Taguchi method, IJAMT, 2006

[8] M.T. Yan, Y.S. Liao; Adaptive control of the WEDM process using the fuzzy control strategy, JMS Vol. 17, 1998

[9] Yan Mu-Tian, Chien Hsing Tsung; Monitoring and control micro wire-EDM process, IJMTM Sc. 47, 2007

[10] H. Dalai, S. Devangan, S. Datta, S.K. Patel, S.S. Mahapatra; A case study on quality and productivity optimization in EDM, AMPT, 2011

[11] Melting Using Element Death, University of Alberta Tutorial

[12] The Finite Element Method and Applications in Engineering Using ANSYS (by Erdogan Madenci and Ibrahim Guven)

[13] ScienceDirect.com

[14] Wikipedia.org